LOGISTIC VEHICLE SYSTEM REPLACEMENT (LVSR) SURVIVABILITY TRADE-OFF ANALYSIS FINAL REPORT

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The United States Marine Corps is considering a crew protection kit as a feature of the LVSR. The purpose of this analysis was to determine the recommended levels of crew cab protection for the LVSR against mines, small arms, and artillery fire. The LVSR program has the goal of fielding a cost-effective, state-of-the-art replacement for the fleet of Logistics Vehicle System (LVS) variants.

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EXECUTIVE SUMMARY

This final report presents the results of a Booz·Allen & Hamilton study to determine the types of potential threats to the Logistics Vehicle System Replacement (LVSR) during future operations and to recommend levels of crew survivability protection for subsequent engineering development. The LVSR program has the goal of fielding a cost-effective, state-of-the-art replacement for the fleet of Logistics Vehicle System (LVS) variants. The USMC is considering a crew protection kit as a feature of the LVSR.

The study team analyzed emerging doctrinal concepts, the mission needs statement, threat lists, the government provided scenarios, and historical mine incident data. Then, the study team determined a ranking of relevant threats. Next, the study team examined survivability design concepts and their design implications. By matching survivability designs concepts against the ranking of relevant threats, the team developed a priority of protection and the resulting recommendations.

The recommended priority of protection is against:

- Mines
- Small Arms
- Artillery Fire

The recommended levels of protection are:

Mines. The recommended design level of protection against mines is an Anti-Tank (AT) blast mine of approximately 8 kg (16 lbs) explosive weight.

Small Arms. The recommended level of design protection should be, at a minimum, against the 7.62mm/5.56mm ball threat fired at zero distance. Both the cab armor and the ballistic glass should be tested against multiple bullet impacts as occurs when automatic fire is employed. The cab roof should be armored to provide protection against 5.56mm/7.62mm small arms fired from an angle of 30^0 below the horizontal. The designer should attempt to design an additional level of small arms protection against a 7.62mm Armor Piercing Bullet threat, but this should be traded-off if necessary to remain within weight constraints.

Artillery. The recommended level of design protection should be initially against the 155mm Fragment Simulating Projectile Standard. Refinement of the design should be an iterative process with the LVSR automotive designers. If the weight of the armor adversely effects roll characteristics, the level of protection should be successively scaled back to get a satisfactory level of automotive performance.

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FINAL REPORT

1.0 INTRODUCTION

This final report presents the results of a Booz·Allen & Hamilton study to determine the types of potential threats to the Logistics Vehicle System Replacement (LVSR) during future operations and to recommend levels of crew survivability protection for subsequent engineering development. This report is prepared for the Naval Surface Warfare Center, Carderock Division (NSWC/CD) under Delivery Order 10, Contract N00167-96-D-0055.

2.0 SCOPE. The stated task[1] is to determine a recommended level of crew cab protection for the LVSR. The task focused on the following two major areas:

- Determine the types of potential threats the LVSR will encounter during both current and future operations conducted within the framework of emerging Marine Corps concepts:
  - Operational Maneuver from the Sea (OMFTS)
  - Ship to Objective Maneuver (STOM)
  - Sustained Operations Ashore (SOA)

- Provide recommendations as to the levels of crew protection and potential solutions that may bring the vehicle up to recommended levels of protection.

NSWC/CD provided the following scenarios for examination:

-Marine Corps Material Handling Equipment (MHE) Study, 1996[2]

-Marine Corps OMFTS Wargaming for Advanced Amphibious Assault Vehicle (AAAV) Concept of Employment, 1996, based on the three standard Marine Corps combat development scenarios.[3]

To further our understanding of mine effects, we reviewed mine incident data and studies from Vietnam, Somalia, and Bosnia as part of the literature search for this study.

This report is unclassified. Classified threat data is contained in separate annexes.

3.0 BACKGROUND

3.1 LVSR Program Information. The goal of the LVSR program is to field a cost-effective, state-of-the-art replacement for the fleet of Logistics Vehicle System (LVS) variants that have been serving the Marine Corps since 1985 as its general-purpose, heavy-haul trucks. Built by Oshkosh as the MK48 Series trucks, the LVS is an 8 x 8, diesel-powered, cab-forward design with an articulated joint that connects the Front Power Unit (FPU) with one of a series of functionally tailored Rear Body Units (RBUs). The FPU contains the cab for the two man crew, the engine, transmission and transfer case. Figure 3.1-1 shows the FPUs/ RBUs configurations:

FPU/RBU	Description	Function
MK48/14	Logistics Platform Truck	Transporting ISO/ANSI containers
MK48/15	Recovery Vehicle	Recovery crane and recovery winch
MK48/16	Truck Tractor	Has fifth wheel, air and electrical connections for trailer hauling
MK48/17	Cargo Truck with Material Handling Crane	Steel cargo body and hydraulic material handling crane
MK48/18	Load Handling System	Reynolds Boughton load handling system for flat rack systems such as the SIXCON Fuel Storage and Dispensing System

Figure 3.1-1 MK48 FPU/RBU Configurations

The FPU and RBU can be de-coupled for transportation as helicopter external-loads. The weight burden of crew cab protection is applied only to the FPU.

The LVSR program is currently in the Milestone 0 Phase of the DOD acquisition process. The program is examining a re-build, re-buy, or re-manufacture option; a procurement of a Non-Developmental Item option; or a procurement of a new design option. Mission Needs Statement (MNS) Log 45 defines system requirements for the LVSR. During FY 98, the program will produce an LVSR Technology Demonstrator for evaluating and refining requirements.

3.2 OMFTS Doctrinal Concepts. Within the overarching operational concept of OMFTS are component concepts such as STOM and SOA. Figure 3.2-1 presents the features of these emerging concepts and their impact on logistics, and hence, the LVSR. The key implication of OMFTS on logistics is the requirement to develop doctrine and equipment that support the OMFTS tenet of reducing the logistics footprint ashore.

Concept	Features	Impact on Logistics
Operational Maneuver From the Sea	-Extended depth. Amphibious forces support from over the horizon, 25 to 40 nm. Ground force objective located 100 mi. inland -No operational pause to secure beach nor for beachhead build-up -Preponderance of fire support from the sea	-Seabasing -Reduce shore requirements, especially fire support and associated ammunition stockpiles -Beach support area minimized
Ship to Objective Maneuver (STOM)	-Maneuver from the ship directly to the objective -Seabasing -Reduction of forces and defensive assets devoted to protect shore sites from ground and air attack	-Large amounts of fuel, ammunition, food, and water rapidly distributed over a much wider and dispersed battlefield than currently required -Reduction in logistics footprint ashore -Logistics information flow must be improved to: --permit anticipatory logistics --permit containerization --allow throughput to user -Smaller distribution sites must be able to displace quickly
Sustained Operations Ashore (SOA)	-Conduct land operations for extended periods of time	-Build-up of supporting infrastructure required -Intermediate combat service support nodes from main off-load point to combat force required -CSS elements need to be mobile to keep up with combat forces

Source: MHE Final Report, 1996[4]

Figure 3.2-1 OMFTS Doctrinal Implications for Logistics

4.0 METHODOLOGY. Figure 4.0-1 shows the steps performed in the analysis leading to the recommendations. Following the figure is a brief description of activities performed during each step.

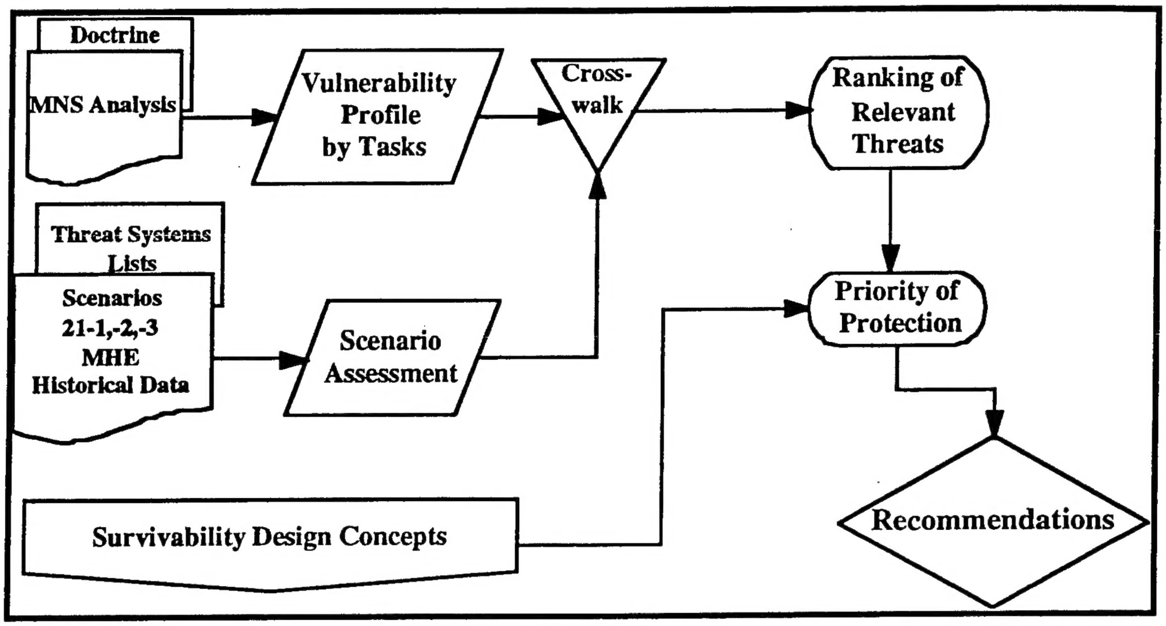

Figure 4.0-1 Methodology

1. **Doctrine and Mission Need Statement Review.** Reviewed emerging doctrinal concepts and the mission needs statement to understand how and where the LVSR would be employed in future operations.
2. **Vulnerability Profiles.** Developed four representative tasks that the LVSR would perform and created a vulnerability profile for each task based on the conditions and threats implied in the tasks.
3. **Scenario Assessment.** Synthesized threat lists, the government provided scenarios, and historical mine incident data, into a scenario assessment.
4. **Cross-walk.** Cross-walked the task vulnerability profiles and scenarios to determine which scenario best covered the analysis requirements.
5. **Ranking of Relevant Threats.** Ranked the threat systems in the selected scenario based on the likelihood of encountering the threat system while performing LVSR tasks. Grouped these threats into major categories, for example, "artillery" or "small arms". Ranked the tasks and associated threats based on LVSR fleet density and proportion of time the LVSR would spend performing a task.
6. **Survivability Design Concepts.** Examined other vehicle survivability design concepts to assess their applicability to the LVSR.
7. **Priority of Protection.** Matched survivability designs against the ranked threats to develop a priority of protection and corresponding levels of protection.

5.0 CONSTRAINTS

The following transportability/weight and cost constraints apply to survivability suites.

5.1 Transportability/Weight. MNS Log 45 defines the transportability requirements for the LVSR[5]. The most constraining requirement is the necessity to carry the FPU as an external load of the CH-53E Helicopter. Under actual conditions, the external load constraint for a helicopter is a function of distance flown, time-on-station, temperature, altitude, and other factors. A reasonable load weight limit is 28,000 pounds[6] for an FPU with a crew protection kit.

5.2 Cost. No firm constraint was set for cost. About 10% ($30k) of the LVSR's estimated total cost per unit ($300K) is an acceptable approximation for the cost of a crew protection kit[7].

6.0 ASSUMPTIONS

1. The study assumes conditions as they are postulated for 2015, especially threat systems availability.

2. Enabling technologies (weapon systems, C4I systems, and aviation systems) can be developed to implement doctrinal concepts of Operational Maneuver From the Sea, Ship to Objective Maneuver, and Sustained Operations Ashore by 2015.

3. The threat heuristic rules of munition selection would be roughly the same as US heuristic rules, such as, "Don't shoot a truck with an expensive Semi-Automatic Command to Line-Of-Sight (SACLOS) missile; save the missile for a more lethal threat such as a tank." This heuristic was a factor in the ranking of relevant threats.

7.0 ANALYSIS. This section provides a description of the work accomplished and its relationship to the methodology described in Paragraph 4.0. The paragraphs below describe the development of the LVSR vulnerability profile, the scenario assessment, the ranking of relevant threats, and the matching of survivability design concepts against the ranked threats.

7.1 LVSR Vulnerability Profile Analysis. A doctrinal review and a MNS analysis provided the information to create the LVSR Vulnerability Profiles.

7.1.1 Doctrinal Review -Vulnerability Reduction vs. Force Sustainment. We began with a review of documentation related to OMFTS, STOM, and Seabased Logistics. As of the date of the documentation (1996-97), the overall operational concepts were clearly defined. The implementing logistics concepts and tactics, techniques, and procedures (TTP) that support OMFTS are still being developed, and draw on planning assumptions regarding major supported/supporting systems in development, such as the MV-22 or the AAAV. Subject to this caveat, a clear OMFTS tenet is to minimize the logistics footprint ashore, allowing for both

increased operational tempo and reduced force vulnerability. Maintaining a minimal logistics footprint ashore reduces the vulnerability of logistics elements, especially the Combat Service Support Detachments (CSSDs) that normally cluster in Beachhead Support Areas (BSAs), at airfields, or in port areas. In these areas, logistics elements become a target for theater ballistic missiles, air-delivered ordnance and long range artillery. On the other hand, some Other Expeditionary Operations (OEO), such as a humanitarian assistance operation, may be performed more efficiently with larger logistics elements ashore, though these operations typically have reduced long-range, indirect fire threat concerns; however, minimizing the logistics footprint is still a desired goal during OEO.

Vulnerability reduction of logistics units must be balanced with the ability to sustain the force. According to Chapter 10, Seabased Logistics, of the OMFTS Implementation Study - Draft Final Report[8]:

- The MAGTF will still depend on the ground mobility systems to provide the bulk of the "just-in-time" support (minimal stockpiling) for large operations.

- Unit field trains will still be ashore.

- Widely dispersed units will require resupply over longer and less secure Lines of Communication (LOCs).

- LOC Security. OMFTS will require the MAGTF's combat units to expend a more focused effort toward maintaining LOCs and providing convoy escort.

As noted above, logistics TTP are still evolving. An example of a CSSD supporting a LAV MAGTF over mostly air-LOCs is documented in Operation Deep Strike[9]. During this exercise, the tasks of LVSs ashore were limited to providing fuel and cargo support to the LAV battalions. Other demonstrated alternative CSSD concepts are: using the CSSD as a small transfer point for supplies, rather than as a large stockpiling point; displacing a series of small CSSDs every 24 hours to reduce vulnerability and to keep up with mobile forces; operating a CSSD in a split configuration, "leapfrogging" its elements, with one element in operation, while the other element displaces forward[10].

7.1.2 MNS Analysis. Figure 7.1-1 shows the LVSR Fielding Plan, as derived from analysis of the mission profiles contained in MNS Log 45[11]. The numbers of LVSRs per unit are shown in the fourth column of this table, the largest number being in the motor transport battalion.

Unit	Task Performed	Configuration	# of LVSRs	Implication
Artillery Regt	-Haul heavy equipment/earth-moving equipment -Move cargo -Augment divisional AAV and LAV haul capability	W/ M870A1 40-ton Lowbed semi-trailer	12	-Cross-country movement w/ trailer
Combat Engineer Bn	Same as above	Same as above	8	Same as above
LAV Bn	Move cargo and bulk liquid to combat vehicles	Tandem tow w/ material handling capability	7	-Cross-country mvmnt -Operations forward of main friendly units common
Tank Bn	Same as above	Same as above	10	-Cross-country mvmnt -Operations on or near the FLOT common
AAV Bn	Same as above	-Same as above -One configured as wrecker/recovery	8	Same as above
Marine Wing Support Group-Fixed Wing	Haul heavy equipment for FARPs -Move cargo (breakbulk and containerized) -Move MWCS Shelters	- With M870A1 40-ton Lowbed semi-trailer -Others configured for cargo containers	24	
Marine Wing Support Group-Rotary Wing	Same as above	Same as above	24	-Cross-country mobility required
Motor Transport Bn	-Haul heavy equipment/ earth-moving equipment/vehicles -Move cargo and bulk liquids	Same as above	204	Missions 70% on-road; 30% off-road
Engineer Spt Bn	Haul heavy equipment and ribbon bridge	W/M870A1 40-ton Lowbed semi-trailer	38	Cross-country mobility required

Figure 7.1-1 LVSR Fielding Plan

Knowing the numbers of LVSR assigned to each type unit enables determination of where the LVSRs will be employed in relation to the Forward Line of Own Troops (FLOT), proximity to the FLOT being a key factor in assessing vulnerability to threats. Figure 7.1-2 shows where LVSRs will be located in relation to the FLOT.

Type Unit	LVSR Proximity to FLOT	Comment
LAV Bn, Tank Bn, AAV Bn	Approximately 3 km behind the FLOT	Possibly includes Motor Transport Bn LVSRs placed under control of Bn S-4s
Artillery Units	Approximately 6-7 km behind the FLOT	
Motor Transport Bn task organized in a CSSD, Marine Wing Support Group	Approximately 15-20 km behind the FLOT or further to the rear	
Combat Engineer Bn, Engineer Spt Bn	Variable	Co-located with supported unit

Figure 7.1-2 LVSR Proximity to the FLOT

7.1.3 Development of the LVSR Vulnerability Profiles. Figure 7.1-3 combines the results of the doctrinal review and the MNS analysis into the resulting LVSR Vulnerability Profiles. The following representative tasks and the analysis presented in Figure 7.1-3 illustrate the principal considerations regarding proximity to the FLOT:

- CSSD Activities. This task represents the activities of LVSRs well behind the FLOT and in semi-fixedlocations.

- Long Haul. This task is used to assess threat vulnerability when LVSRs are moving on possibly unsecured LOCs, normally well behind the FLOT. A large number of LVSRs in the motor transport battalion would be engaged in this task.

- Resupply of Combat Vehicles. This task includes the organic LVSRs of the LAV, tank, and AAV battalions conducting resupply of maneuver units from the unit trains forward to within 3 km of the FLOT.

- Support of Artillery Firing Units. This task was identified as a separate task for vulnerability assessment because of the unique requirement to be in close proximity to artillery units which are subject to counterbattery fire.

Task	Cbt Svc Spt Det (CSSD) Activities	Long Haul	Resupply of Cbt Vehicles (LAV, Tank, or AAV)	Support of Artillery Firing Units
Activities	-Transfer of supplies -Limited stockpiling	-Movement over ground LOCs -Convoys	-Refuel/rearm one terrain feature back from FLOT (approx 3 km)	-Upload ammunition within close proximity to firing positions (approx 6 km from FLOT)
Considerations				
Combat Troops Assigned To Provide Security?	-Yes, but may be required to provide own security	-Up to platoon size escort	None, security provided by troops in proximity	None, security provided by proximity to firing unit
Within Range of Enemy Arty Fire?	-Positioned out of range of medium artillery, if possible (15-20 km from FLOT)	Potentially, when closing on maneuver battalion area	Yes	Yes, subject to counter-batteryfire
Within Direct Fire Range of Main Enemy Forces?	No	No	Possible, but should be terrain masked	No
Target of Enemy Special Operations Forces?	Yes	Yes	No	No
Target of Enemy Airstrikes?	Yes	Yes, if enemy air capable of route interdiction	Only as a target of opportunity	Only if airstrikes are part of enemy counterfire plan
Target of Enemy Theater Ballistic Missiles?	Yes	No	No	No
Engineer Support Available for Mine Detection/Clearing?	Yes	Yes, but mines may be re-emplaced	No, but assume maneuver unit will recon/ clear resupply sites	No, but assume firing unit will recon/ clear site; however, scatterable mines may be part of enemy counterfireplan

Figure 7.1-3 LVSR Vulnerability Profiles

7.2 Scenario Assessment. Examination of the three standard Marine Corps Scenarios, the MHE Scenarios, and the AAAV wargame report provided assessments for the following top-level threat categories: Air, Theater Ballistic Missile, Special Purpose Forces, Armed Insurgents, Mine Capability, Artillery Capability, Offensive NBC Capability. Annex A (Classified) shows the rating of these threats in general terms (Low, Mid, High) for each scenario.

Figure 7.2-1 shows the results of a cross-walk between scenarios and tasks from the vulnerability profiles. This figure reflects whether the LVSR must perform certain tasks within a given scenario.

Scenario	Task			
	CSSD Activities	Long Haul	Resupply of Cbt Vehicles	Support of Artillery Firing Units
MC 21-1	Yes	Yes	Yes	Yes
MC 21-2	No	No	Mostly restricted to Fuel	No
MC 21-3	Limited to airport evac site	No	Mostly restricted to Fuel	No
MHE Korea	Yes	Yes	Yes	Yes
MHE SWA	Yes	Yes	Yes	Yes
MHE Humanitarian Relief	Yes	Yes	No	No

Figure 7.2-1 Scenario vs. Task Crosswalk

Since MC 21-1 represented the most comprehensive employment of the LVSR, it provides the required traceability for a detailed threat systems-level assessment. Note that the MHE Scenarios did not provide threat systems lists.

7.3 Ranking of Relevant Threats. The likelihood an LVSR would encounter a given threat type and the general location of an LVSR during performance of its tasks were the most significant factors determining threat ranking. Applying military judgment, and receiving feedback/ confirmation from MCIA and PM-CSLE, allowed for rank ordering the threats. Annex B contains tabulated assigned rankings. The final rank ordering of relevant threats is shown in Figure 7.3-1.

Threat Ranks	
Type Threat	Rank
Mines	1
Rocket Propelled Grenades (RPGs)	2
Small Arms	3
Artillery	4
Multiple Rocket System (MRLs)	5

Figure 7.3-1 Ranking of Relevant Threats

7.4 Survivability Design Concepts. The next step in the analysis examined other survivability kit design programs to determine the potential to leverage these programs for LVSR crew protection kit design. The design implications shown in Figure 7.4-1 served as the guide for determining the relevance of the programs described below.

Type Threat	Design Implications
Mines	Design against the AT blast mine
RPG	Armor protection not within weight constraints
Small Arms	-Design against common manportable calibers -Consider depressed rifle threat in MOUT, as well as side threats
Artillery	-Design against 155mm fragmentation effects -Roof armor (overhead protection) limited by roll problems -Trade-off protection to stay within weight limits
MRL	-Accept level of protection provided within artillery standard -Trade-off protection to stay within weight limits

Figure 7.4-1 Design Implications for Ranked Threats

7.4.1 Discussion of Parallel Design Efforts. The following sources provide information on existing US truck crew protection kits:

- US Army Operational Requirement Document (ORD) for the Tactical Wheeled Vehicle Crew Protection Kit (CPK)[12] (hereafter referred to as the CPK ORD). Driven by operational requirements that are based on recent experience in Somalia and Bosnia, this 1996 document specifies crew protection levels for wheeled tactical vehicles against mines, small arms, and artillery. Two levels of protection are specified: "Required" and "Desired", as shown in Figures 7.4-3 and 7.4-4.

- Tank-Automotive Command Research, Development, and Engineering Center (TARDEC) Briefing on US Position for NATO Standard for Tactical Wheeled Vehicle Crew Protection Kits[13]. TARDEC has been tasked to develop the US position on a NATO Standard. This briefing specifies low, medium, and high levels of protection against mines and small arms, and discusses artillery protection.

- Live Fire Testing of Palletized Load System (PLS) Kit Test against a Mine[14]. The US Army conducted a live-fire test at Aberdeen Proving Ground of a crew protection kit mounted on the PLS, a cab-forward truck built by Oshkosh, in some ways similar to the LVS. The test data contains results of an actual mine shot and corresponding data on recorded seat acceleration/deceleration effects. In addition to cab armor, the tested package included a hydro-pneumatic seat to protect the neck and the spine against acceleration/deceleration injuries.

7.4.2 Mines. An excellent summary of the mine threat, effects, and design considerations are contained in mine papers presented at the annual TARDEC-sponsored Ground Vehicle Survivability Symposiums[15]. Figure 7.4-2 shows a summary of mine kill mechanisms. These papers point out that a cab crew protection design requires consideration of all mine effects. Designing solely against one kill mechanism may actually magnify the effects of another kill mechanism.

Mechanism	Counter	Comment
Fragmentation	Armor	Similar effect from improvised explosive devices and smaller UXO (grenades and bomblets)
Blast	V-shaped hull or blast deflector	Vehicle designed to allow venting of blast away from the crew
Vehicle Deformation	Spall liner, strength of structural members	Design considerations must be balanced against countering gross vehicle movement
Loss of Vehicle Control	Second steering axle	Also counter by reducing speed to under 25 mph
Gross Vehicle Movement	Energy absorbing members, V-shaped blast deflectors, collapsible seats, harnesses	-Design considerations must be balanced against countering vehicle deformation -Lighter vehicles most susceptible
Large Impulse Fragments (Overburden)	Heavy armor	Dependent on soil conditions
Shaped Charges	None, yet	Counter by detection

Source: "Conventional Landmine Kill Mechanisms" by Schneck et al. [16]

Figure 7.4-2 Mine Kill Mechanisms

Design requires specification of a type mine (anti-personnel vs anti-tank, blast mine vs shaped charge/platter charge mine) and the mine's explosive weight. Figure 7.4-3 shows some proposed standards for mine protection.

Level of Protection	Explosive Weight	Typical Mine
CPK ORD Required	12 lbs	-
CPK ORD Desired	16 lbs	-
TARDEC Proposed NATO Low	6 kg/13.2 lbs	Soviet TM-57
TARDEC Proposed NATO Medium	8 kg/17.6 lbs	Soviet TM-62
TARDEC Proposed NATO High	10 kg/22 lbs	US M-15

Figure 7.4-3 Proposed Mine Levels of Protection

The proposed standards are all against Anti-tank (AT) blast mines. The design against an anti-personnel (AP) mine provides a level of protection that includes smaller improved conventional munitions (ICM) encountered as unexploded ordnance (UXO). However, experience in both Somalia and Bosnia show that a wheeled vehicle is more likely to be the victim of an AT mine or a large command-detonated mine[17] (See also Annex C). Another design consideration is whether to design protection against the more widely available blast mine or against the more lethal and

sophisticated shaped charge or platter charge type mines. The blast mine is more prevalent, and more likely to be encountered in Third World Nations. While the shaped charge/platter charge type mine is more lethal, cost considerations restrict its use to the richer Third World nations and the major powers. Though its kill mechanism is not yet defeatable[18], its electric and metallic components make it more easily detected or countered. The Soviet TM-62 is the most commonly encountered AT blast mine[19]. The TM-62's 7 kg explosive weight places it in the 80th percentile of mine explosive weights[20]. Therefore, the recommended design level of protection is to the proposed NATO Medium standard - an AT blast mine of 8 kg explosive weight (Figure 7.4-3).

7.4.3 Rocket Propelled Grenades (RPGs) or Equivalent Weapons. The term "RPG" commonly means a class of shoulder-fired weapons using a shaped charge warhead as a kill mechanism. The LVSR is vulnerable to armed insurgents or special purpose forces use these weapons while conducting ambushes on LOCs, in the context of the "Long Haul" task, or conducting raids on a logistics site, in the context of the "CSSD activities" task. RPGs are commonly available, and, as they were designed to defeat tank armor, it is not feasible to design armor protection within LVSR weight constraints. For example, unclassified data credits the Soviet RPG-7, commonly available throughout the Third World, with being capable of penetrating 400mm (15.7 inches) of rolled homogenous armor plate[21]. The RPG threat must be countered by tactical means, such as convoy procedures, convoy escort, route security patrols, and perimeter security.

7.4.4 Small Arms. In terms of armor design, the term "small arms" is commonly defined as projectiles up to and including 14.5mm. Design of cab protection requires specification of a caliber/ type bullet, range to target, and the angle of obliquity to target to determine thickness of material (Figure 7.4-4). If the material is sufficiently thick, the armor will also protect against the directional-type AP mine (similar to the US M18 Claymore series mines). Usually, two materials are involved: armor for most of the cab area and ballistic glass for the windows.

Level of Protection	Bullet	Range	Angle
CPK ORD Required	7.62mm M80 Ball	100m	0^0
CPK ORD Desired	7.62mm B32 API	100m	0^0
CPK ORD Overhead	7.62mm	100m	30^0
TARDEC Proposed NATO Low	7.62mm M80 Ball/5.56mm Ball	0m	0^0
TARDEC Proposed NATO Medium	7.62mm AP	0m	0^0
TARDEC Proposed NATO High	7.62mm SLAP/Cal.50 M2 AP	100m/500m	0^0

Figure 7.4-4 Proposed Small Arms Levels of Protection

7.4.4.1 Threat Caliber/Type Bullet. As described in Paragraph 7.4.3, the LVSR is vulnerable to ambushes and raids. Besides RPGs, the forces conducting these operations will use automatic weapons, up to light machineguns of 7.62mm caliber. Standard ball ammunition is the most commonly fired bullet from machineguns in this caliber, since personnel are their primary target. Against certain types of armor, the higher velocity 5.56mm NATO ball has better penetration than the 7.62mm NATO ball[22]. Armor piercing bullets, though more costly, are available in these

calibers for use against light armor or against personnel in body armor. A recent development is the existence of 12.7mm (caliber .50) single shot or semi-automatic sniper weapons[23], that are also man-portable, weighing approximately 30 lbs. These weapons would more likely be used against high value targets (radar, electronics, parked aircraft) than as the weapon of choice in an ambush or raid, where a heavy volume of suppressive fire is required. Therefore, kit design should consider the 7.62mm/5.56 mm ball as the most common threat and explore the possibility of providing protection against 7.62mm armor piercing bullets.

7.4.4.2 Range. The CPK ORD specifies a range to target of 100 meters for 7.62mm threats. Under jungle conditions or Military Operations on Urbanized Terrain (MOUT), the ambushing force could be much closer, so our assessment is that designs should initially consider a 0 meter range for the case of a "zero distance" ambush.

7.4.4.3 Angle of Obliquity. Generally, design requirements are stated against the worst case, a projectile impacting at 0^0 obliquity, or at right angles to the armor. Under MOUT conditions, overhead protection should be a consideration. The CPK ORD recommends protection be designed against small arms fired at a 30^0 angle of depression from the horizontal, which equals a 60^0 angle of obliquity at the target. For the LVSR design, our assessment is that a 0^0 angle of obliquity should be used for all surfaces except for the cab roof, which should use the level of protection as stated in the CPK ORD.

7.4.4.4 Recommendation. The initial design of the small arms protection should be against the 7.62mm/5.56mm ball threat fired at zero distance. Both the cab armor and the ballistic glass should be tested against multiple bullet impacts as occurs when automatic fire is employed. The designer should attempt to incorporate additional protection against the 7.62mm Armor Piercing bullet, but this should be traded-off if necessary to remain within weight constraints

7.4.5 Artillery. Design of cab protection requires specification of an artillery projectile and distance to target. These are used to select an equivalent fragment simulating projectile (FSP), fired at a specified velocity at the armor during testing to determine thickness of material. In our analysis, the principal artillery threats were to LVSRs performing the tasks of "resupply of combat vehicles" or "supporting artillery firing units". Both of these tasks require cross-country mobility and making full use of the current LVS's ability to handle roll motion of up to six degrees either above or below the horizontal. According to TARDEC (AMSTA-TR-R), armoring the cab roof leads to design trade-offs on roll characteristics of the vehicle[24]; design of the roof armor would be an iterative process with the LVSR automotive designers, starting with a threat-based level of protection, which would be successively scaled back to get a satisfactory level of automotive performance.

The CPK ORD specifies a 155mm artillery shell, fired at a range of 60 meters from the target. Most of the threat artillery weapons systems in the scenarios analyzed ranged from 122mm to 152mm (with longer-ranged guns in a counterbattery role generally being 130mm or larger), so a 155mm shell is considered a good approximation of threats. Any consideration of projectiles

larger than 155mm was ruled out, since it was judged that some aspects of 155mm-level protection would be traded-off to stay within weight limits. Even though the LVSRs dedicated to supporting the artillery firing units make up a small proportion of the LVSR fleet, their high potential for exposure to counterbattery fire suggests that the need for a special kit for artillery LVSRs should be further evaluated.

7.4.6 Multiple Rocket Launchers (MRLs). The same comments and assessments that apply to artillery protection design generally apply to MRLs. Threat MRL warheads ranged in caliber from 122mm to 240mm. Again, we concluded that the LVSR should be protected up to the 155mm FSP standard, with protection traded-off to stay within weight limits.

8.0 CONCLUSION

Figure 8.0-1 shows the final threat ranking and recommended priority of protection for the LVSR.

Threat Type	Priority of Protection	Comment/ Recommendations
Mine, AT Blast	1	1. Use TM-62M Standard (approx. 16 lbs explosive). 2. Must protect against fragmentation effects and acceleration/ deceleration effects.
Mine, AT Shaped Charge	Not Survivable	1. Revisit if composite materials technology improves/ becomes cheaper. 2. Countermeasures are detection (higher metallic content).
Mine, AP	Effects included in Mine, AT Blast	1. Lesser blast and fragmentation than AT Mine. 2. For directional Claymore-type mine, effects should be countered in conjunction with small arms threat.
RPG	Not Survivable	Revisit if composite materials technology improves/becomes cheaper.
Small Arms	2	1. Limit to commonly manportable calibers (5.56mm and 7.62mm). 2. Should protect against multiple impacts.
Artillery	3	1. Use 155mm FSP standard. Few countries use 105mm shells. Also larger caliber artillery generally employed in counterbattery role. 2. Consider specialized kit for LVSRs supporting artillery batteries. 3. Moving targets (convoys) less vulnerable to targeting.
MRL	No special design consideration	Fragmentation effects for warheads smaller than 155mm covered by artillery requirement. Protection for 240mm MRL incurs excessive weight penalties.

Figure 8.0-1 Recommended Priority of Protection

8.1 Priority of Protection/Levels of Protection. The recommended priority of protection is:

- Mines
- Small Arms
- Artillery Fire

8.2 Recommended Levels of Protection

8.2.1 Mines. The recommended design level of protection against mines is an AT blast mine of approximately 8 kg explosive weight. A representative mine of this class is the Soviet T-62M. The crew protection kit developer must simultaneously design protection against fragmentation, blast, and acceleration/deceleration effects. Pending development of proven armor technology against the shaped charge mine, the AT shaped charge mine will have to be countered by detection methods. Protection against AT blast mine fragmentation effects will counter the fragmentation effects of the AP mine. For reasons explained in Paragraph 7.4.2, the use of an AP mine as a design standard is considered insufficient protection in view of mine incident experience in both Bosnia and Somalia.

8.2.2 Rocket Propelled Grenades. Current technology cannot provide armor protection against the RPG within the LVSR's weight constraints. Barring a break-through in armor technology, protection against RPGs should not be a design requirement.

8.2.3 Small Arms. The recommended level of design protection should be, at a minimum, against the 7.62mm/5.56mm ball threat fired at zero distance. Both the cab armor and the ballistic glass should be tested against multiple bullet impacts as occurs when automatic fire is employed. The cab roof should be armored to provide protection against 5.56mm/7.62mm small arms fired from an angle of 30^0 below the horizontal. The designer should attempt to design an additional level of small arms protection against a 7.62mm Armor Piercing bullet, but this should be traded-off if necessary to remain within weight constraints.

8.2.4 Artillery. The recommended level of design protection should be initially against the 155mm FSP Standard. Refinement of the design should be an iterative process with the LVSR automotive designers. If the weight of the armor adversely effects roll characteristics, the level of protection should be successively scaled back to get a satisfactory level of automotive performance. There is no additional design requirement recommended for protection against MRLs.

8.3 Additional Observations

8.3.1 NATO Crew Protection Kit Standards. The implementation of a NATO standard on crew protection kits for tactical wheeled vehicles will impact future design requirements. Recommend that NSWC/CD remain in contact with TARDEC to monitor status and planned implementation date of any NATO standard.

8.3.2 Payload Protection. While outside the scope of this study, this issue surfaced during the course of the analysis. The main points in this discussion were as follows:

- Ammunition Payload Protection. For the artillery LVSRs subjected to counterfire, the value of crew cab protection may be greatly reduced if, knowing the vulnerability of ammunition payloads, the crew chooses to abandon the vehicle and temporarily seek cover elsewhere. This issue should be studied separately.

- Troop Carrying Protection. Protection of troops transported in the cargo compartment involves severe weight penalties. While protection against horizontal small arms threats can be reasonably added, as was done by TARDEC in a prototype kit for a 5-ton cargo truck, response to the mine threat involves providing protection against blast, fragmentation, acceleration/deceleration effects of the same magnitude as those experienced in the cab[25]. If there is any interest in this area, recommend NSWC/CD follow-up with TARDEC.

8.3.3 Mine Detection and Neutralization. While mine detection and neutralization means are outside the scope of this study, they are important means of responding to mine threats. Shaped charge mines, platter charge mines, and off-route mines firing shaped charged rockets cannot yet be reasonably countered with armor within LVSR weight constraints. Development of detection and neutralization means against these specific threats should be further investigated.

8.3.4 Leverage US Army PLS Kit Development to Meet LVSR Requirements. Aberdeen Proving Ground conducted a live-fire mine shot against this kit. Two promising developments from the PLS Kit were the hydro-pneumatic seat to protect against acceleration/deceleration effects and the fact that the total kit weight was approximately 2000 lbs[26].

8.3.5 Obtain Enough Cab Armor Kits to Outfit LVSRs Operating in High Threat Areas. Costing will be developed by the cab kit developer, and will be a function of lot size. The pattern of USMC deployments since DESERT STORM has been generally in regimental-size or smaller task forces. If cost per unit prohibits outfitting the entire LVSR fleet, then recommend buying enough kits to outfit a portion of the fleet and prorating the cost across the LVSR fleet to obtain an acceptable unit cost.

8.3.6 Design all LVSR with Kit Interfaces Built-In. Feedback provided by PM-CSLE representatives is that, during a deployment, equipment that is not accessible for training and easily installed gets left behind in the warehouse. Another reason for easily mounted kits is the potential requirement for installing kits on the LVSR while on ships at sea.

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13. Meeting between NSWC-CD, and TARDEC (AMSTA-TR-R), 12 Feb 98. (hereafter, TARDEC 2/12).

14. TARDEC 2/12.

15. Papers include "The Antipersonnel Mine Threat", Harry (Hap) Hambric and William Schneck, Fort Belvoir, VA, 1996; "The Development of Mine Resistant Vehicles", William Schneck, Fort Belvoir, VA 1994; "Conventional Landmine Crew Kill Mechanisms", Schneck et al, 1994; "The Vehicular Mine Threat", Harry Hambric and William Schneck, Fort Belvoir, VA 1994.

16. "Conventional Landmine Crew Kill Mechanisms", Schneck et al, 1994.

17. See "After Action Report: Operation Restore Hope", Schneck, BRDEC, 13 Jun 94, Appendix B and "CCIR for DCSENG, HQ USAREUR: Task Force Eagle Mine Strike Summary", dated 25 May 96.

18. There has been South African research and development into countering shaped charge mines by suspending a composite material plate below the vehicle to disrupt jet formation. Drawback is that it magnifies acceleration effects when a blast mine is detonated instead of a shaped charge mine. Extracted from "Notes on Visit of Dr. Vernon Joynt, Garth Barrett (sp) and others to BRTRC, 21 Jun 96", provided by Mr. Noel Wright, CECOM RDEC.

19. TARDEC 2/12. Also, see the "The Vehicular Mine Threat", Hambric and Schneck, Fort Belvoir, VA 1994, p. 76.

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ACRONYMS AND ABBREVIATIONS

AAAV	Advanced Amphibious Assault Vehicle
AAV	Amphibious Assault Vehicle
ACTIV	Army Concept Team In Vietnam
ANSI	American National Standards Institutes
AP	Armor Piercing
AP Mine	Anti-Personnel Mine
APC	Armored Personnel Carrier
AT Mine	Anti-Tank Mine
Bn	Battalion
BRDEC	Belvoir Research, Development, and Engineering Center
BSA	Beachhead Support Area
CECOM	Communications Electronics Command
C4I	Command, Control, Communications, Computers, and Intelligence
CCIR	Commander's Critical Information Requirements
CH	Cargo Helicopter
CPK	Crew Protection Kit
CSS	Combat Service Support
CSSD	Combat Service Support Detachment
DCSENG	Deputy Chief of Staff, Engineer
Det	Detachment
FARP	Forward Arming and Refueling Point
FLOT	Forward Line Own Troops
FPU	Front Power Unit
FSP	Fragment Simulating Projectile
HMMWV	High Mobility Multipurpose Wheeled Vehicles
ICM	Improved Conventional Munition
ISO	International Standards Organization
km	kilometers
LAV	Light Armored Vehicle
lbs	pounds
LOC	Lines of Communications
LVS	Logistics Vehicle System
LVSR	Logistics Vehicle System Replacement
MAGTF	Marine Air-Ground Task Force
MC	Marine Corps
MCCDC	Marine Corps Combat Development Command
MCIA	Marine Corps Intelligence Activity
MHE	Material Handling Equipment
MK	Mark
mm	millimeter

MNS	Mission Need Statement
MOUT	Military Operations on Urbanized Terrain
MRL	Multiple Rocket Launcher
MV-22	Marine Variant, V-22 Osprey
MWCS	Marine Wing Control Squadron
nm	nautical miles
NSWC/CD	Naval Surface Warfare Center/ Carderock Division
OEO	Other Expeditionary Operations
OMFTS	Operational Maneuver From The Sea
ORD	Operational Requirements Document
PLS	Palletized Load System
PM-CSLE	Program Manager-Combat Support and Logistics Equipment
RBU	Rear Body Unit
Regt	Regiment
RPG	Rocket Propelled Grenade
SACLOS	Semi-Automatic Command to Line-Of-Sight
SECMA	Study and Evaluation of Countermine Activities
SIXCON	Type of Fueling System
SLAP	Saboted Light Armor Penetrator
SOA	Sustained Operations Ashore
Spt	Support
STOM	Ship To Objective Maneuver
Svc	Service
SWA	South West Asia
TARDEC	Tank-Automotive Command Research, Development and Engineering Center
TNT	Trinitrotoluene
TOSOM	Threat Oriented Survivability Optimization Model
TRADOC	Training and Doctrine Command
TTP	Tactics, Techniques, and Procedures
USAREUR	US Army Europe
USMC	United States Marine Corps
UXO	Unexploded Ordnance

ANNEX B
Methodology for Ranking of Relevant Threats

Ranking of Relevant Threats. Using the threat systems list associated with MC 21-1, threat systems were ranked for each LVSR task based on likelihood of encounter. Likelihood of encounter is a function of expected range to the threat, threat munitions selection heuristics, and normal tactical employment factors. The TOSOM MC 21-1 threat systems list[27] provided the basis to construct a threat list analysis spreadsheet, using the system description, weapons class, and weapon description fields. Jane's defense publications[28] provided additional unclassified range data. Figure B-1 presents generally accepted artillery positioning rules of thumb used during in the assessment.

Type Artillery Force	Normally Positioned Behind FLOT
US -Trained	1/3 range of standard projectile
Soviet -Trained, Regimental Artillery Group	3-5 Km
Soviet -Trained, Division Artillery Group	5-8 Km

Figure B-1 Artillery Positioning Rules

The threat list analysis spreadsheet was used to tabulate the assigned rankings, then sorted to group the highest ranked threats. Grouping these threats into major categories (for example, "artillery" or "small arms") produced a ranking of threats by task. Figure B-2 shows the assessments, based on commonly accepted military judgment, used to combine these four sets into one ranking for design purposes.

Assessment	Rationale
Determined threats to "Long-Haul" rank highest	-Highest density of LVSRs in Motor Transport Bn; these LVSRs will spend the bulk of their time in this profile
Ranked threats to "Resupply of Combat Vehicles" second	-Lower density of vehicles -However, closest proximity to FLOT
Ranked threats to "Support of Artillery Firing Units" third	-Lowest density of vehicles -However, exposed to counterbattery fire
Ranked threats to "CSSD Activities" fourth	-Other survivability options are more likely to be used

Figure B-2 Assessed Threat Ranking by LVSR Task

The rationale for ranking the threats to "CSSD Activities" last was based on information provided by PM-CSLE. Under emerging OMFTS concepts, the CSSD will be smaller (supply transfer points, not supply stockpiles) and displace more frequently (roughly every 24 hours). This would limit the time available for engineers to construct field fortifications[29]. On the other hand, a displacement every 24 hours would reduce the enemy's ability to acquire and target the CSSDs, reducing vulnerability.

The final ranking of relevant threats is shown in Figure 7.3-1 in the main body of the report.

ANNEX C
Historical Mine Threat Data

C.1 Introduction. The data shown in this annex provides supporting evidence for some of the conclusions reached in the threat analysis. Since World War II, mines have caused a significant portion of US casualties, as shown in Figure C-1. This trend leads to the conclusion that mines will continue to be a significant threat in future warfare.

Conflict	Vehicles	Personnel	Mine Incidents per Day	Incidents per Thousand Soldiers per day
Korea	56 %	10%	-	-
Vietnam	70%	33%	8.17	0.016
Persian Gulf	60%	35%	-	-
Somalia	60%	26%	0.07	0.005

Source: Hambric and Schneck, "The Vehicular Mine Threat"[30]

Figure C-1 US Historical Loss Rates to Mines

C.2 Lessons Learned from Vietnam. In 1968, the Army Concept Team In Vietnam (ACTIV) published its "Study and Evaluation of Countermine Activities (SECMA)" Report[31]. This study was based on combat vehicle loss data during 1967 and 1968 in Vietnam, in-country testing of captured enemy mines, and testing of add-on protection kits for the M113 series APC. Since casualties from M113 mine incidents represented 45% of total casualties produced by mines, the main study focus, understandably, was to test a kit to protect the M113. Some of the findings from this study:

- Mines with charge weights estimated by field personnel to be in excess of 20 lbs, represented 35.9 % of the mines reported from 1 Mar 68 to 10 Jun 68, indicating a trend of the enemy using large anti-vehicular mines.
- The loss rate for military wheeled vehicles during the period 1 Apr 67 to 29 Feb 68 was less than 1%. The highest rate was 2.3% for 5-ton dump trunks (due to the use of the 5-ton dump trunks as a proofing vehicle in mine clearing operations), the only wheeled category to exceed 1%.
- In 41 incidents involving 5-ton trucks (cargo and dump), the total casualty rate was 0.49 casualties per detonation, in contrast to a 0.29 casualty rate per detonation for tanks, and a 2.5 casualty rate for M113s.
- Losses were concentrated among combat troops clearing routes, serving as convoy escorts or engaging in offensive operations.
- The mine threat to wheeled vehicles did not warrant the use of composite materials. It should be noted that because of weight and power constraints, the only material considered for mine protection for wheeled vehicles was a reinforced composite that cost $68 per square foot (1967 dollars) - which was a cost prohibitive option.
- Investigated the use of seats with collapsible columns, but drew no conclusions due to lack of instrumentation.

C.3 Somalia. Figure C-2 shows a summary of mine incidents that occurred in Somalia from Dec 92 to Mar 94. Some of the data is incomplete, especially that pertaining to UN vehicles not directly under US control.

Type Mine (# Incidents)	Type Vehicle and # of Incidents		# Incidents with Casualties	Mine Description	Comment
AT Mine (5 Incidents)	Toyota Landcruiser	1	1	US M-7	
	HMMWV	1	1	Belgian PRB M-3	
	M-88 Armd Recv'y	1	None	Double-stacked TM-46	
	UN Veh (type not specified)	2	Data not available	AT Pressure Fuzed	Two separate incidents; further data not available
Command Detonated (Improvised Explosive Device) (7 Incidents)	5-ton Tractor	1	None	30 lbs (est. explosive wt.)	
	HMMWV	2	2	30 lbs, 60 lbs	
	2 1/2 ton	2	1 (1 unknown)	40 lbs, 30 lbs	
	UN Veh (type not specified)	1	Data not available	Data not available	Data not available
	Puma	1	None	Size unknown	Zimbabwe inherently mine-resistant vehicle
Total		12	5 of 8 (known)		Data not avail in 4 incidents

Source: Schneck, "After Action Report, Operation Restore Hope[32]"

Figure C-2 Mine Incident Summary, Somalia

Notable is the absence of AP mines. The Somalis used either AT mines or command-detonated improvised explosive devices of very large explosive weight.

C.4 Bosnia. Figure C-3 shows a summary of mine incidents that occurred in Bosnia from Dec 95 to May 96, within the 1st (US) Armored Division's Task Force "Eagle", which included the Nordic Brigade and a Russian Brigade. There are indications that heavier mine casualties were experienced by UN forces prior to the implementation of the Dayton peace accords.

Type Mine (# Incidents)	# of Incidents per Initiator		# Incidents with Casualties	Metallic Mine	Non-metallic Mine	Data Not Specified
AP Mine (9 Incidents)	Tracked	3	None	-	1	2
	Wheeled APC	1	None	-	-	1
	On Foot	4	4	1	1	2
	Helicopter (hovering)	1	None	1	-	-
AT Mine (10 Incidents)	Tracked	8	3	1	2	5
	Wheeled	2	2	1	-	1
Total		19	9 of 19	4	4	11

Source: HQ USAREUR, "CCIR for DCSENGR, 25 May 96[33]

Figure C-3 Task Force "Eagle" Mine Strike Summary
Bosnia (30 Dec 95-1 May 96)

In US units, strict convoy procedures were in effect. Generally, logistics units were not involved in mine incidents. Mine incidents generally involved units responsible for route security, route reconnaissance, and route clearing operations, so during this phase of the operation, the predominant types of vehicles involved in mine incidents were tanks or APCs. The two wheeled incidents involved AT mines against a HMMWV and a Mercedes jeep, resulting in destruction of the vehicles and casualties in both incidents.

C.5 Conclusion. The data from Vietnam, Somalia, and Bosnia indicates a trend of large mines being used in the anti-vehicle role. Hence, protective kits for wheeled vehicles must be designed against the AT mine-level threat.